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What can we expect from Europe's Carbon Capture and Storage demonstrations?

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Abstract

Carbon capture and storage (CCS) on electricity generation and energy intensive industry is expected to play a considerable role in achieving the European Union's decarbonisation goals. EU CCS demonstration project funding has been created to encourage development and accelerate commercial CCS deployment by providing funds to bridge the capital gap for early commercial-scale CCS installation. Eleven CCS project proposals currently remain at least nominally active, but reduced funding and other constraints suggest delivery of at best around a third of these. To explore how these demonstrations impact on the scale of subsequent CCS deployment in the EU three simple scenarios for post-demonstration CCS activity and deployment (none, limited and considerable) are considered and examined in the context of key factors that have influenced the demonstration programme. Without strong political support for post-demonstration deployment including measures such as strategic storage validation and $CO_2$ pipeline planning, and a clear process to make CCS commercially attractive to investors on a timeline consistent with climate ambitions, even a positive result from the demonstration programme is unlikely to enable CCS to deliver as expected.

Keywords

CCS; Demonstration; EU ETS; NER300

## Introduction

The EU has considerable ambition for carbon capture and storage (CCS) to play a major role in decarbonisation efforts. The EU Commission's Energy Roadmap 2050 [1] – outlining EU energy policy options required to achieve the goal of 85-90% cut in $CO_2$ emissions by 2050 envisages a 19 to 24% contribution to total reductions by CCS in all but the very high renewables scenario. To make such a contribution, CCS deployment is envisaged in the period 2020-2030, with CCS applied to all coal and gas power plant by 2030, and around half of the EU's heavy industry by 2050.

However, attempts to launch the technology at commercial scale in the EU through public co-funding of CCS demonstrations projects are struggling. At present, operating commercial-scale CCS is limited to a handful of facilities globally – mostly gas processing (e.g. Statoil's Sleipner gas platform, Norway) in which the $CO_2$ capture is a well-established and integrated process. None of these are located in the EU.

To try to launch CCS application to fossil power plant and energy intensive industries (e.g. steel and cement manufacture) publicly co-financed CCS demonstration project programmes are underway in much of the developed world including the European Union - “up to twelve”[1], UK - “four projects”[2], USA - “five to ten”, Canada - “up to six”, Australia - “three to five” and Norway - “one to two” [2]. To date, only four full-chain commercial scale CCS demonstration projects (two in Canada two in the US) have so far taken positive final investment decision and commenced construction [3].

The EU CCS demonstration programme is designed principally to inform on two fundamental subjects: the technical possibility of CCS and the cost of the technology. It will also strongly indicate the stakeholder (government, business/industry and publics) acceptability of the application of CCS at scale [4]. Composed of two funds – the New Entrants Reserve 300 (NER300) of the EU Emissions Trading Scheme (EU ETS), and the European Economic Recovery Programme (EERP) – it aims to include the full range of currently available capture technologies (pre-, post-, oxy-combustion for electricity generation and methods applicable to industrial capture) and storage solutions (on and offshore depleted hydrocarbon fields and saline aquifers) and be applied on both power and industrial plant. The results are intended to provide technical understanding and initial cost discovery for commercial scale CCS [5].

Eleven EU CCS project proposals currently remain at least nominally active (Table 1), but reduced funding and other constraints suggest delivery of at very best around a third of these, and likely someway behind the originally envisaged timetable of operation by 2015.

Table 1: Current EU CCS demonstration projects (2012). Abbreviations: Post – post combustion capture; oxy – oxyfired capture; pre- pre-combustion capture; EERP – European Economic Recovery Plan funding; NER1 – New Entrants Reserve 300 round 1 funding; UK – UK CCS commercialisation programme funding; FEED – Front End Engineering and Design.

| Country | Project | Capture | Storage | Funding | Status comment |
|---|---|---|---|---|---|
| UK | Peterhead (gas) | Post | Offshore - depleted gas | NER1? UK? | Storage site FEED completed |
| | Drax (coal) | Oxy | Offshore – aquifer | NER1? UK? | |
| | ~~Don Valley~~ (coal) | Pre | Offshore – $CO_2$-EOR | EERP (€180mn) | Cancelled following withdrawal of UK Government support (October 2012) [6] |
| | Teeside (coal) | Pre | Offshore | NER1? UK? | |
| | Captain (coal) | Pre | Offshore | UK? | Not an applicant to NER round 1 |
| Netherlands | ROAD (coal) | Post | Offshore - depleted gas | EERP (€180mn) + NL (€150mn) | All FEED completed and permitting near completion (2012) |
| | Green Hydrogen (hydrogen) | Cryogenic | Offshore - depleted gas | NER1? | |
| France | Floranges (steel) | Top gas | Onshore – | NER1? | Host facility facing uncertain future |

[1] The announced ambition of the European Council in 2007 – now expected to deliver at best around a third of this number of projects.
[2] The UK Government competition is separately run to the EU funding mechanisms, but demonstration projects in the UK are at least partially expected to be included in the EU ambition through co-funding.

| | | | | | |
|---|---|---|---|---|---|
| | | recycling | aquifer | | following closure of blast furnace (Oct 2012) |
| Italy | Porto Tolle (coal) | Post | Offshore – aquifer | EERP (€100mn) + NER1? | Subject to permitting challenge (overruled 2011) |
| Spain | Compostilla (coal) | Oxy | Onshore – aquifer | EERP (€180mn) | Not an applicant to NER round 1 |
| Poland | Belchatow (coal) | Post | Onshore - aquifer | EERP (€180mn) + NER1? | |
| Romania | Getica (coal) | Post | Onshore – aquifer | NER1? | |

Now that this much reduced practical shape of the EU CCS demonstration programme is emerging, we can revisit and reflect on the outcomes that are looked for: what is realistically achievable from the CCS demonstrations as they stand today? What issues will remain to be explored? To explore this, three basic scenarios for post demonstration CCS deployment in the EU – none, very limited and considerable are presented. These are then considered in the context of major influencing factors raised by and/or facing CCS demonstration in the EU: public opinion, $CO_2$ transport and storage infrastructure development, the carbon market and emissions reductions mandating, enhanced oil recovery, and gas power generation. What has the demonstration programme told us about these factors to date? How much will they impact upon deployment of CCS subsequent to the demonstration programme, and to what degree might a successful demonstration outcome (or otherwise) be able to influence these factors?

<u>Basic EU CCS deployment scenarios</u>

Broadly, there are three possible scenarios for commercial CCS (non-)deployment following different demonstration outcomes – none, limited, and considerable – briefly outlined below.

1. *None*

Demonstrations show large-scale deployment of CCS to be too technically challenging. This scenario might arise because for instance capture processes prove unsatisfactory at commercial scale, because storage at the scale required is shown to be technologically unreliable, or because government, industry and other stakeholders fail to create a sufficiently encouraging environment for continued CCS activity [7]. Under this scenario, there is no CCS expansion beyond the first (essentially unsuccessful even if completed) demonstration projects, and the current considerable “wedge” [8] of CCS in EU $CO_2$ emissions reduction scenarios will need to be reconsidered. Electricity generation has alternatives, though their deployment on the scale required to fully replace fossil fuel generation currently seems very challenging. Industrial emissions would (unless the facilities closed) remain an insoluble problem without unprecedented innovation.

2. *Limited*

Technical issues prove resolvable and storage is shown to be viable. However, the overall costs of CCS in especially power generation are in almost all cases commercially unattractive compared to alternative options. Prohibitive costs might arise from, for instance, additional as yet unforeseen technical costs, financial structure and liability problems and/or public and political rejection of preferential (cost-effective) plant, pipeline and storage sites [9].

In this scenario, in the initial post-demonstration period CCS would at best be used very minimally in the power sector as a bridging technology [10]. This might take the form of retrofitting CCS on a very limited number of existing coal power plant where its installation is a sensible management of generation assets and/or fuel stock, but almost no new coal power with CCS would be built in the EU in the 2020s and beyond. However, where does this leave gas power and energy intensive industry? To achieve consistency with emissions reduction ambitions, both will either need to apply CCS from around the mid-2020s onwards, or be massively reduced in scale. With regard to gas, a broadly negative experience of CCS demonstration would likely dampen government and industry enthusiasm for a large scale deployment of CCS – but would sufficient alternatives be available? The issues around gas are examined in Section E below. For industrial sources, very limited existing CCS deployment – point capture to point storage, or small regional clusters in geographically convenient locations – would have little potential for easy connection or expansion to include large quantities of industrial sources. Unless industrial sources were able to fund (or be funded for) CCS expansion, closure seems the most likely alternative.

3. *Considerable*
CCS proves both technically viable and economically credible under carbon pricing, emissions and low carbon generation subsidy policies, and for electricity generation cost competitive with renewables and nuclear. Under this scenario, power companies currently heavily invested in fossil fuel, especially those which own considerable coal assets, might retrofit existing and/or build new plant with CCS. This large scale of CCS operations would require long-distance (and trans-national) $CO_2$ pipeline networks that enable shared access to large storage resources, e.g. saline formations beneath the North Sea [11, 12]. The existence of such infrastructure would enable relatively straightforward and economical connection of additional sources (gas and industry) as required.

Influencing factors
The above are three very basic scenarios. To examine their likelihood, five interrelated factors that impact technical possibility, cost and stakeholder acceptability: public opinion, pipeline and infrastructure development policy, carbon markets and mandating of CCS, enhanced oil recovery potential and most importantly the role of gas, are now examined. These have already had considerable impact on EU CCS demonstration efforts, and how they are addressed will have a huge influence both on the outcomes of demonstration, and on the scale and shape of any post demonstration CCS deployment.

A. *Public opinion.* There is considerable trepidation in both industry and government regarding social acceptance of the demonstration projects and subsequent CCS deployment. To date, experience with public opinion regarding CCS development has been mixed and the underlying reasons multifaceted and to a degree project specific [13]. Onshore $CO_2$ storage has perhaps caused the greatest concern, both with regards to its safety, and – especially when located remote from the economic benefit (jobs) of the $CO_2$ source – the question of "why here – what's in it for us?" Different projects have experienced different levels of opposition. Where a localised benefit (job preservation and creation) is perceived by communities a less negative reaction has generally resulted. However, where a project is planned in an area of vibrant economic activity, the apparent benefits for employment may not be so attractive, and building new infrastructure in a crowded or picturesque area may also not be an attractive option for local residents.

Research also shows that local public's concerns often additionally relate to the broader direction of national energy policies and to the role of technologies and options including CCS, nuclear, renewables, demand reduction and so forth. When faced with the option of CCS, local publics frequently begin to question how low-carbon energy development is being thought about and planned, stimulating questions that are not easily answered by CCS developers (who, by definition, are focused only on CCS).

The candidate CCS demonstration and pilot $CO_2$ injection projects at Compostilla and Hontomin (Spain), and the full chain CCS pilot at Lacq (France), have had relatively positive experience with local governments and communities. These projects have it appears gained better support both through a degree of existing local experience of subsurface industry, and the fostering of good local connections between the project developers (including research institutes in several cases) and the community by efforts to consult and involve local stakeholders from the early stages of project planning.

To date, CCS demonstration projects cancellations resulting in the large part from public opposition to onshore storage have occurred in Germany and the Netherlands, while projects featuring incomplete CCS on new coal have been abandoned in the UK due to strong opposition to further unabated coal power. With respect to storage, successful less controversial (offshore storage) demonstration projects may gradually help to allay fears, but could equally result in the position that if $CO_2$ storage works offshore – why bring it onshore? With no demonstrations yet being built let alone operating this is too early to tell, but widespread rejection of onshore storage would certainly increase the costs and complexity, and thereby both slow and limit the potential for EU-wide CCS deployment [11]**.** Additionally, while the current focus of public concern has been on storage, actual projects, involving for instance the construction of visually large chemical capture facilities might well result in new concerns.

B. *$CO_2$ pipeline infrastructure.* CCS deployment scenarios 2 and 3 both require $CO_2$ pipeline beyond that built for demonstration projects. In the case of the UK and the Netherlands, both of which have regions containing multiple demonstration project proposals, it is inefficient to build single point to point transport pipelines for each project [14-16]**.** NER300 funding allows project proposals to apportion some of their expected infrastructure costs to 'partner' projects with the caveat that the project has access to sufficient funds to go it alone if necessary. Demonstration-phase clusters would also enable practical experience of the regulatory, commercial and contractual formulations required for sharing pipeline and/or storage facilities –

important to enabling larger-scale network development as part of commercial deployment – though at the risk of this greater complexity slowing demonstration project delivery.

The general location of the major potential storage sites that would be required in the case of scenario 3 are known, as (although these could change) are the expected locations of major concentrations of source facilities (both power plant and industry) [17]. The major unknown element of the equation is the volume of $CO_2$ that will require transportation. This is why the European Commission, discussing $CO_2$ infrastructure in its proposed EU Energy Infrastructure Package [18], has difficulty defining "known needs" and "unknown needs". $CO_2$ volume remains for the present an "unknown". There is certainly potential for a degree of over-sizing of initial CCS pipeline infrastructure on a reasonable "no-regrets" basis as has been shown by studies in both the Netherlands [19], and the UK [14] to enable local clusters to develop quickly. However, the large-scale deployment described in scenario 3, especially if onshore storage remains politically difficult, will require a much larger trans-European pipeline network (comparable in scale to present natural gas transmission networks) connecting source regions to major storage locations [11].

The eventual $CO_2$ pipeline and storage infrastructure demand presently remains an unknown. However, major trans-European pipeline developments, and storage site appraisals (especially in the case of relatively under-researched to date saline aquifers) have long lead times often of around ten or more years. Given this, early strategic planning of priority corridors, hub locations, and evaluation and initial exploration of large capacity storage options is essential to enable the large scale deployment of CCS on the timescale consistent with achieving its desired role. Without this preparation, large-scale CCS deployment will be at best significantly delayed, and might even prove unattainable, even if CCS demonstration projects themselves prove successful. Such preparation, while inexpensive compared to the actual costs of the infrastructure itself, is probably too speculative to be undertaken solely by industry and requires strategic activity by government. Leveraging demonstration projects to assist in this process, by acting as seeds to future $CO_2$ transport and storage networks should be strongly encouraged [20]. Relevant actions would include widening key pipeline wayleaves such as those on foreshores to allow for efficient parallel expansion, and using small amounts of the captured $CO_2$ for test injections into potential future stores in the vicinity of the primary store – e.g. saline aquifers nearby a depleted gas-field storage site.

C. *Carbon markets and mandating*. The EU ETS, the centrepiece of EU climate policy, is now entering its third phase. Thus far, due to a structural oversupply of EU Emissions Allowances (EUAs) resulting from a series of demand (the 2008 financial crash and subsequent recession), and supply (overlap with other decarbonisation policies) shocks, the EUA price (< € 8/t$CO_2$ – 2012) has fallen well below that envisaged to encourage decarbonisation activity including the adoption of CCS [21]. Its reform – e.g. through the set-aside of EUAs is an area of active discussion [22].

Alternative measures to prevent new unabated coal power construction, and possibly encourage CCS adoption beyond the existing capital funding (EERP and

NER300) for demonstrations are an active area of policy debate at both regional, national and EU scale [23]. In terms of preventing new unabated coal, of the six CCS demonstration projects awarded support under the EERP, fully three are in *de facto* 'any new coal must have CCS' mandating regimes, due to national or local government policy to not permit new coal power plant unless CCS is used. These projects are: Don Valley (UK) – cancelled in October 2012, subject to the UK government's policy commitments in the Electricity Market Reform package for "no new coal without CCS and an emissions performance standard (EPS)" [24]; Jänschwalde (Brandenburg, Germany) – cancelled in December 2011, subject to the regional government's policy of "no new coal without CCS"; and ROAD (Rotterdam, Netherlands) where the Rotterdam Climate Initiative has a commitment to a "50% reduction in $CO_2$ by 2025, relative to 1990" [25] – by implication no new coal without CCS.

As the struggles of the demonstration programme to date have seemingly demonstrated, even with large capital grants, the expense and risk of CCS is commercially unattractive. Encouraging CCS adoption in the power sector requires market incentive that makes it at least (if not more given the technology risk) attractive as the alternatives – either in the form of a sufficiently high EUA price and/or preferential electricity pricing and grid access. A modified EUA price would have to be high enough to make in the first instance CCS on coal power (subject to fuel costs), competitive with unabated gas power and the same applies for preferential electricity pricing. The UK government is (on paper at least) leading on this, with proposals in the Electricity Market Reform package to introduce a fixed price for CCS power generation at a level competitive with renewable or nuclear subsidy [24].

Demonstration projects have a critical role to play in establishing both the capital and operating costs of CCS in the power sector. However, to ensure they can fulfil this role, they need to happen. It is perhaps unlikely that any EU ETS reform will have taken sufficient effect on the price of EUAs to adequately incentivise the imminently needed demonstration project investment from industry, so a generous preferential pricing regime (and/or priority grid access) targeted specifically at demonstration projects should be strongly considered to help secure this crucial investment. Government has a stark choice – keep to the current arrangement and risk CCS demonstration programme failure, making deployment scenario 1 (no deployment) very likely, or recognise that the current support is insufficient and apply corrective measures that ensure demonstration project delivery.

D. *Enhanced oil recovery (EOR)*. Since first undertaken in the Sacroc field (Texas) in 1972, $CO_2$-EOR activity has continually expanded across the oil producing region of the southern US. While the original Sacroc field injection used $CO_2$ from a nearby gas processing facility, the expansion of $CO_2$-EOR was largely enabled by the plentiful supplies of $CO_2$ found in natural $CO_2$ reservoirs such as the McElmo Dome (Colorado). As these natural sources have depleted, interest in sourcing man-made $CO_2$ has increased, with many gas processing facilities in the region now selling $CO_2$, which requires scrubbing in any case from the gas, for use in $CO_2$-EOR operations instead of venting it. This value for $CO_2$ (currently around \$20-30/t$CO_2$) provides potential revenue for CCS power and industry projects. The two power plant CCS demonstrations that have taken final investment decision and commenced construction – Kemper County IGCC (Mississippi, US)[3], and Boundary Dam (Saskatchewan, Canada) both have contracts in place for sale of captured $CO_2$ for $CO_2$-EOR.

What possibility is there for $CO_2$-EOR in and around the EU – primarily in the North Sea? The situation is markedly different to that in North America in a number of aspects. Europe's oilfields are located offshore which not only adds to the overall complexity of any $CO_2$ injection operations, but also means that depleting oilfields have generally already undergone additional recovery by injection of (plentiful) seawater. The geology of North Sea oilfields is also different to that found in the primary $CO_2$-EOR region - the Permian Basin in the southern US. The thicker and more compartmentalised reservoirs of the North Sea are thought to make sweeping the reservoir with $CO_2$ less effective than in the thinner layered reservoirs found in the Permian Basin. However, initial studies indicate that $CO_2$-EOR in the North Sea might still prove commercially viable (Scottish Carbon Capture and Storage, 2009). The biggest issue for North Sea $CO_2$-EOR is arguably the lack of sufficient quantities of easily available $CO_2$ [26].

CCS demonstration projects have the potential to change this[4]. The 2CO Don Valley (UK) demonstration proposal envisaged storage (and additional revenue) from $CO_2$-EOR in the North Sea [27], and $CO_2$-EOR was also strongly considered for the Green Hydrogen project (Netherlands) [16]. However, in October 2012 the Don Valley project failed to secure UK Government funding [6] leaving North Sea $CO_2$-EOR potential an open question that none of the remaining demonstration proposals seek to address. While reliance on revenues from $CO_2$-EOR has been viewed as increasing the project risk, should it have proven technologically and economically successful, it had the potential to play a significant role in stimulating subsequent CCS deployment in NW Europe. It remains to see if new $CO_2$-EOR proposals are made (e.g. for NER round 2), or perhaps as additional operations subsequently connected onto demonstration projects.

E. *Gas.*

Natural gas is expected to play a growing role in the EU's energy mix [1], both from domestic sources (with shale gas development possibly replacing depleting production from conventional fields), and from outside the EU via pipeline or LNG shipping. In the short term, replacing unabated coal capacity with gas does offer significant advantages – halving $CO_2$ emissions per unit electricity, reducing air pollution, and, depending on the specifics of the gas plant built potentially enabling better balancing of intermittent renewables. However, caution must be exercised that this does not 'lock-in' large amounts of unabated fossil capacity. Theoretically, the EUs 'capture-ready' feasibility assessment requirements for new gas power plant

[3] Construction of Kemper County IGCC is presently (2012) on hold following legal challenge of rate recovery arrangements following increase in the project's capital cost.

[4] While use of $CO_2$ for EOR does not necessarily involve monitored and verified storage, EU funded CCS with EOR projects will be subject to the monitoring and verification requirements of the EU $CO_2$ storage directive.

should encourage thinking around enabling for retrofitting, but to date capture-readiness is having limited effect (e.g. in encouraging appropriate siting of new gas plant for easy connection to storage – [28]).

Longer term (2030-2050) emissions targets are only consistent with either CCS on gas, or very limited gas generation, but the gas industry is as yet not receiving a clear message on the determination of policy ambition. As an example, while the UK Government in 2010 followed the recommendation of the UK Committee on Climate Change (UKCCC) to formally open its CCS demonstration programme to gas power projects [29], it subsequently announced policy intention to enable 'grandfathering' of gas power plant consented under a soon to be introduced Emissions Performance Standard of 450g/kWh (consistent with modern unabated CCGT plant) until 2045 [30] and 'gas continuing to play an important role in the energy mix… beyond 2030..[not] restricted to providing back up to renewables'. The UKCCC has declared this position to be 'incompatible with meeting legislated carbon budgets' [31].

This situation is also impacting on CCS demonstration in the power sector more broadly. Persuading investors to favour expensive (and untried) coal with CCS, over unabated (though possibly) 'capture-ready' gas requires either a very high carbon price and/or very high gas price [32] – neither of which seem likely at present.

The first set of publicly funded CCS demonstrations in Europe are unlikely to include a gas power plant project. The EU 2050 Energy Roadmap [1] envisages CCS on gas 'from around 2030 onwards', but only one gas power project has been submitted for EU funding (Peterhead, Scotland) and the assessment of the round 1 NER300 projects by the European Investment Bank on a cost per unit $CO_2$ emission abatement achieved gives strong preference to funding CCS on coal [33]. The Peterhead proposal ranked lowest on the European Investment Bank's NER round 1 assessment of project proposals [34].

However, gas generation with CCS may offer overall advantage over coal generation with CCS. $CO_2$ separation from gas fired power is more challenging due to the lower concentration of $CO_2$ in the flue gas, but the overall penalty of CCS on plant efficiency can be lower than for coal, and per unit electricity produced, the volumes of captured $CO_2$ requiring transport and storage are significantly reduced (around 50% lower) [4]. The selection and assessment criteria for the second phase of the NER300 (funds from the auction of the remaining 100 million EUAs) remains to be defined. There is a strong case to either specify gas power generation as a category, or to assess the power projects proposals on the cost per unit of low carbon electricity, a metric under which CCS gas is expected to be competitive with CCS coal. This represents a crucial opportunity to establish utility confidence in the technology in a timeframe allowing for CCS on gas deployment consistent with the proposals of the EU Energy 2050 roadmap. To encourage such deployment, exploration of how gas with CCS can be appropriately incentivised to make it commercially attractive also needs detailed policy discussion. For instance, early gas plant with CCS (and therefore higher levilised opex), would have to co-exist with unabated gas plants (lower levilised opex). What level of carbon price would be needed to make operation of the gas plant with CCS favourable? Would other measures – e.g.

enabling some flexibility of the $CO_2$ capture allow for better overall (from both a cost and emissions perspective) operation of the electricity system? Further, while the EU is currently falling behind competitor markets in CCS on coal [35], CCS on gas offers an opportunity for European industry to take a leading role in the technology, building on work undertaken at the pilot facilities at Lacq, France [36], and Mongstad, Norway [37].

The degree to which gas explicitly features in the EU's CCS demonstration programme and the debates around commercial incentives/mandating of CCS may, indeed, prove the *single* most important factor affecting the chance to grow a major European CCS sector: if the sector includes gas, it will achieve commercial scale; if it excludes gas, it will start small and likely remain small. Unless sufficient alternatives emerge, such an outcome could represent a major barrier to achieving overall energy decarbonisation. Gas, initially unabated, but subsequently with CCS has the potential to play a huge role in decarbonising the EU's energy sector [38]. However, proactive policy, learning from the lessons of coal CCS demonstration, and addressing gas-specific requirements is critical to enabling its delivery.

<u>Outcomes of CCS demonstration</u>

What, therefore, can we look for from the demonstration programme? Eleven EU CCS project proposals currently remain at least nominally active, but reduced funding (resulting from the low EUA price and constrained national budgets) and the other constraints outlined above suggest delivery of at best around a third of these. The first hurdle is the confirmation of sufficient co-funding from EU Member States for the first round of the NER300 to be awarded, and for the selected projects to be in a position to take a positive final investment decision. Should this not happen, the future role of CCS in the EU would be in very serious doubt – it is highly unlikely that sufficiently serious and coordinated political will to undertake and fund a fresh demonstration programme would be forthcoming. Even if commercially proven CCS technology were imported from elsewhere at a later date, its overall contribution to emissions mitigation would likely be much smaller than currently envisaged. As a result EU emissions mitigation strategy would have to be rapidly re-thought, without reliance on any sizeable amount of CCS. This outcome maps to deployment scenario 1 (none), or at best scenario 2 (limited).

Should a small number of demonstration projects proceed, then, approaching 2020, the EU CCS demonstration programme will be in a position to be able to answer the fundamental question of technical possibility of CCS for (at least) coal power generation. It should also deliver some degree of cost discovery and experience of how CCS operates in the carbon market, and provide some limited information on public opinion regarding active CCS operation. Depending on the specific projects chosen, they could establish some early pipeline infrastructure of likely use to future networks, and (should new proposals emerge) undertake initial exploration of $CO_2$-EOR possibility. This experience of CCS demonstrations will probably determine whether or not CCS deployment will occur (scenarios 2 – limited, and 3 – considerable), or be found to be too challenging to pursue further (scenario 1 – none).

Nonetheless, the first generation of CCS plant will certainly be unable to accurately predict which of the deployment scenarios 2 or 3 is most plausible. While demonstrations will provide considerable education on the cost of CCS technology, as experimental first-of-a-kind facilities they are unlikely to become reference plant that set industry standards. Regarding storage and infrastructure, demonstrations will again test feasibility in individual cases, but won't be able to conclusively prove whether or not there is sufficient politically and commercially acceptable storage and pipeline for large scale deployment [39]. Most critically, while successfully demonstrating CCS on coal will help to build a case for further deployment, it must also be demonstrated on gas. Here, the second phase of the NER300 has a critical role to play in filling gaps in both the geographical spread of projects, and their fuel-type and $CO_2$ capture technology.

Assuming that CCS demonstrations prove CCS viable, we must recognise that the road to aspired levels of deployment will remain long and steep. Continued political will translated into active, consistent and coherent policy remains the essential ingredient to determine the overall success and scale of CCS as a mitigation method both in Europe and indeed worldwide. Without this action, CCS in the EU is at best likely to be deployed slowly and with little overall reach [40] – perhaps restricted to a few advantageous niches. To enable significant deployment, Government must commit to actively supporting CCS beyond demonstrations – addressing public concerns, enacting supportive market measures, and in critical areas through direct funding contributions towards the capital expenditure of planning and developing CCS pipeline and storage infrastructures beyond, and building on those associated specifically with demonstration projects.

Following successful demonstration, in return for continuing political (and financial) support, industry should accept regulation (through reform of the EU ETS, and additional measures such as emissions performance standards) that ensures the application of CCS on a timetable consistent with delivering the EU's emissions reduction objectives.

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